

Technical Report 427

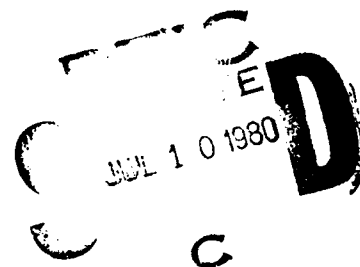
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**EVALUATION OF A GUNNERY SIMULATOR'S
VISUAL DISPLAY AND SEVERAL STRATEGIES
FOR LEADING MOVING TARGETS**

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U. S. Army

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gunners to classify target speed as either fast, medium, or slow and to apply one of three corresponding leads should prove an effective lead strategy. Application of the data to the gunnery model demonstrates that selection of a cognitive strategy for training may have an impact on operational performance. The current research will be of value to instructional system developers, because it demonstrates the importance of unobservable processes, such as cognitive strategies, for training.

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**EVALUATION OF A GUNNERY SIMULATOR'S
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FOR LEADING MOVING TARGETS**

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Training Simulators

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FOREWORD

The Fort Knox Field Unit of the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) has conducted this research as part of an in-house investigation of simulators for training. This research is responsive to the requirements of the Directorate of Training Developments, USAARMS, Ft Knox, Kentucky under Human Research Needs 78-140, "Conduct of fire maintenance of gunnery proficiency," and 78-161, "Feedback characteristics of training devices and simulators" and the objectives of RDTE Project 2Q762722A777, FY 78.


JOSEPH ZEIDNER
Technical Director

EVALUATION OF A GUNNERY SIMULATOR'S VISUAL DISPLAY AND SEVERAL STRATEGIES FOR LEADING MOVING TARGETS

Brief

Requirement:

The Ft Knox Field Unit of ARI evaluated the gunnery training provided by a conduct of fire trainer, the Chrysler Fire Control Combat Simulator (FCCS). The present research investigated whether a simple visual display, such as that of the FCCS, contains the cues necessary for training moving-target gunnery. It further investigated the kind of lead strategy best suited for moving target gunnery in the simulator. This report discusses the potential of various lead strategies for use in the field.

Procedure:

Armor trainees viewed FCCS displays containing a moving target and judged (a) various distances between points in the display, (b) target ranges, and (c) the slant of the ground upon which the target moved. One group of trainees also judged the target's speed to the nearest 5 mph, while another group simply classified target speed as either slow, medium, or fast.

Findings:

Both groups of trainees systematically underestimated distances in the display and also underestimated target ranges. They systematically overestimated the slant of the ground from the horizontal. Although judgments based on the simple FCCS display were systematically in error and revealed large individual differences, the judgments were qualitatively similar to those reported in several previous field studies and in other research on space perception.

In addition to errors in judging distances, ranges, and slant, trainees were very inaccurate in judging the speed of a moving target to the nearest 5 mph in the simulator; speed judgments also showed large individual differences. However, trainees categorized the three target speeds as fast, medium, or slow with relative accuracy. Parameters reflecting speed judgment performance were derived for both of the speed judgment conditions, and were applied to a tank gunnery model.

This analysis revealed a large difference in expected hit probabilities for the two different approaches to judging target speed. Requiring gunners to categorize target speeds and to apply one lead for each category restricts the huge variability that occurs when observers judge target speed in miles per hour, and also covers the speed range of the 1980's battlefield more effectively than a single standard lead. Hence, a categorization strategy could potentially produce a dramatic superiority in hit probabilities over a strategy requiring gunners to calculate lead based on judgment of target speed, or one requiring gunners to use a single standard lead.

Utilization of Findings:

This research has several implications for training moving target gunnery:

(a) Since the pattern of spatial judgments in the simplified display of the FCCS did not differ markedly from patterns of spatial judgments obtained in past research on space perception, it may be unnecessary to incorporate high-fidelity displays in simulators intended to train basic principles in leading moving targets. The very simple displays of the FCCS allowed gunners to categorize target speeds quite well; accurate categorization of target speeds should produce effective gunnery performance, provided appropriate training is given. However, gunnery training with evasive targets, training of battlesight techniques, or training of adjustment of fire techniques such as Burst-on-Target (BOT) may require a much richer display than that of the FCCS. The fidelity necessary for a general-purpose conduct-of-fire-trainer should be determined.

(b) Given the extreme variability of observers' speed judgments (in the FCCS and in the field) when they are asked to estimate target speed in miles per hour, it is unreasonable to attempt to teach a lead strategy that requires gunners to calculate lead based on exact target speed. The variability of perceived speed indicates that simply allowing observers to practice leading moving targets and providing them with knowledge of results will probably be ineffective. Even if a target moves at a constant actual speed, its perceived speed will vary over time, and a trainee will not experience a constant relationship of perceived speed to required lead. This psychophysical variability necessitates the use of a strategy that will restrict gunners' response variability, such as a categorization strategy. Furthermore, the difficulty of complex mental calculations for the average gunner plus the difficulty of remembering formulas for calculating lead and carrying out the required lead calculations under the stress of combat discourages attempts to train lead calculation based on judgment of target speed.

(c) Further research also must be conducted to determine the optimal number of speed categories for training when targets can move at any speed within the range anticipated for ground targets on the 1980's battlefield. Effective training on engaging moving targets may require presenting targets across the entire range of possible speeds for categorization.

The current research also has implications for the development of instructional systems:

(a) It emphasizes the importance of unobservable processes, such as cognitive strategies, for training.

(b) It provides an example of a methodology for assessing the expected impact of training alternative strategies on operational performance.

This research illustrates that the amount of fidelity required in a simulator depends on the task to be trained. While subjective impressions may lead one to ask for high fidelity, efficient task performance may often be trained on simple simulators if the task demands are brought into agreement with trainees' cognitive and perceptual abilities.

EVALUATION OF A GUNNERY SIMULATOR'S VISUAL DISPLAY AND SEVERAL STRATEGIES FOR LEADING MOVING TARGETS

INTRODUCTION

Problem. Simulation will play an increasingly important role in gunnery training in the future. It is important to determine the amount of fidelity and detail required in a simulator's visual display for training various gunnery tasks. Too little fidelity will produce ineffective training, while too much fidelity incurs needless expense. One area of increasing importance for training, and hence for simulation, is moving target gunnery.

Moving targets present a complex problem in tank gunnery. In order to hit a moving target, the gunner must apply the correct amount of lead; for a given kind of ammunition, the correct lead depends primarily on the target's speed. Training gunners to estimate the speed of a moving target in order to apply the correct amount of lead therefore presents a major training problem. This training problem exists not only for tank fire control systems without automatic lead, but also for "degraded mode" gunnery in systems with automatic lead when the lead function is inoperative. Gunners must learn an efficient and effective strategy for applying different leads to different speed targets in either case.

Background. ARI recently evaluated several facets of the gunnery training provided by a conduct-of-fire simulator, the Chrysler Fire Control Combat Simulator (FCCS). With the FCCS, trainees use realistic gunner's controls to move a computer-generated reticle upon a CRT display and "fire" a simulated round at the target. Although the computer-generated visual display of the FCCS is quite simple (as Figure 1 shows), it can present a moving target. Unlike the single-speed moving targets usually presented to trainees, the FCCS can present a target moving at one of three different, pre-programmed

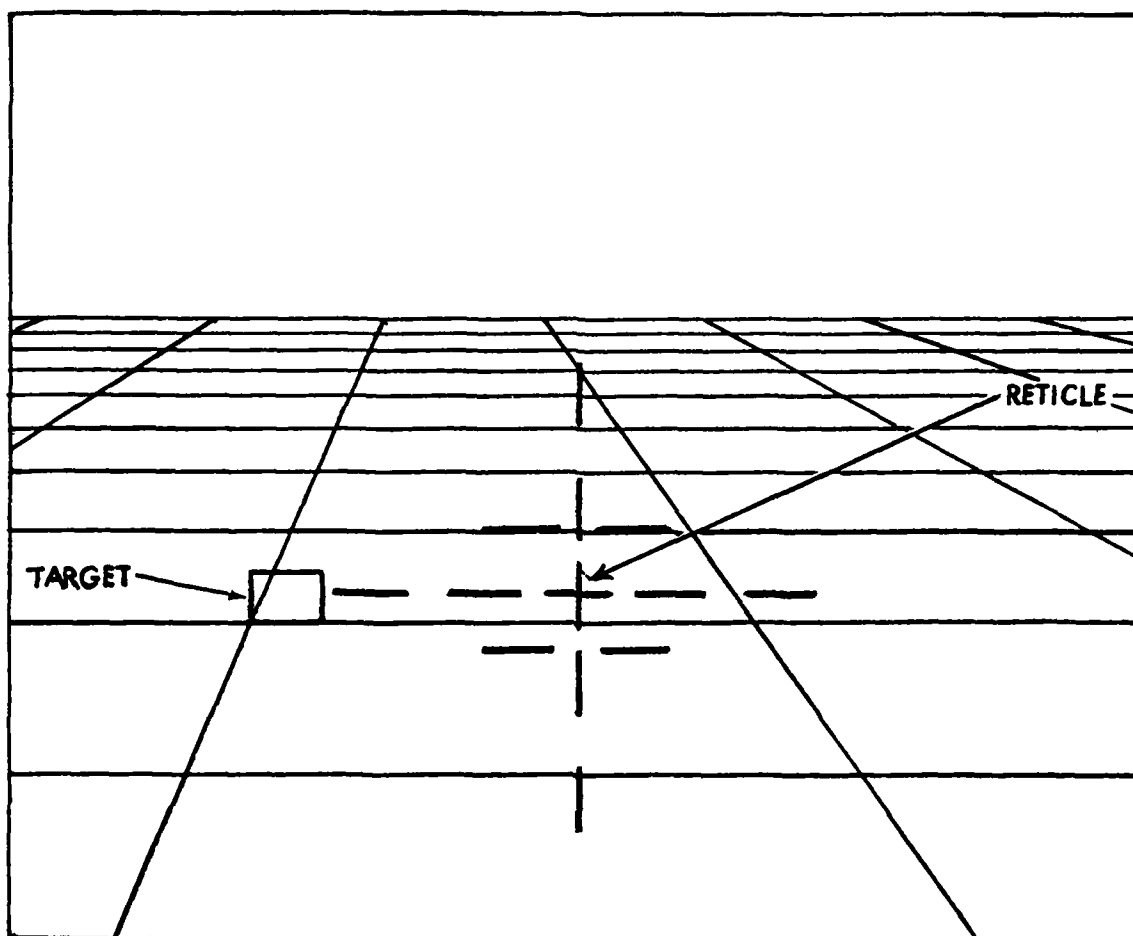


Figure 1. Visual Display of the Chrysler FCCS.

speeds; the instructor simply selects the target speed prior to each engagement. The flexibility of the FCCS potentially allows valuable training on engaging moving targets, but the simplicity of its display raises the question of whether it contains enough information to allow effective training.

Several requirements for the visual display of a conduct of fire trainer come to mind immediately. First, the display must appear three-dimensional to lend realism to the simulation. Second, it must represent distances and ranges adequately. Third, for the trainer to be useful for training moving target gunnery, it must represent target speed adequately. To accurately represent a three-dimensional space and the speed of a target in the space, one would suspect that the display of a conduct of fire trainer must incorporate the major monocular cues to depth. These are generally considered to be: (1) the familiar size of objects (one can infer the distance of a familiar object such as a car by its projected size in the visual field), (2) linear perspective (the apparent size and spacing of lines reduces with increasing distance from the observer -- for example, railroad tracks appear to converge in the distance), (3) texture gradients (the apparent size of objects decreases regularly and their apparent density increases regularly with increased distance from the observer -- for example, clods in a plowed field appear smaller and denser in the distance than they do nearby), (4) height in the visual field (farther objects tend to be higher in the visual field than nearer objects), (5) monocular motion parallax (objects at different distances from the observer appear to move across the visual field at different speeds as the observer moves), (6) inter-position (farther objects are blocked from view by nearer objects), and (7) aerial perspective (objects in

the distance appear somewhat hazy and have a bluish color relative to nearer objects). The FCCS display clearly does not incorporate all these cues, and incorporates some only partially (refer again to Figure 1). Rather than several familiar objects, the display contains a single, rectangular target. While the lines of the grid comprising the ground converge into the distance, their thickness does not decrease as it would in a real, three-dimensional scene. The display fails to incorporate either a texture gradient or aerial perspective. The current research investigated the effect of these shortcomings.

Since no simulator can be evaluated independently of the task it will be used to train, questions about whether the FCCS display contains sufficient information for training gunners to engage moving targets cannot be asked without reference to the kind of lead strategy that is trained. Therefore, this research not only addressed the adequacy of the FCCS display, but investigated its potential in training different strategies for leading moving targets.

Several kinds of lead strategies have been proposed for engaging moving targets. These strategies, discussed below, differ primarily in the demands placed on the gunner to judge the target's speed accurately.

The first, and least demanding lead strategy, requires gunners to apply a single standard lead to all moving targets, regardless of speed. This strategy will be referred to as the Standard Lead strategy. Current Armor doctrine indorses this strategy in FM 17-12-2. If a simple display, such as that of the FCCS, fails to provide sufficient information for observers to determine anything about target speed, then the single Standard Lead strategy

is the only feasible alternative for training with the simulator. The obvious strengths of a single Standard Lead strategy are simplicity in training, and speed of firing the first round against a moving target. However, one must consider that a single lead covers only one small part of the speed range expected from targets on the modern battlefield. Furthermore, the lead specified in FM 17-12-2 is optimal only for targets moving at approximately 10-12 mph (when firing APDS ammunition); one can reasonably assume that vehicles on the modern battlefield will move at much higher speeds than this.

The second, and slightly more demanding kind of strategy, requires gunners to categorize target speed into one of a number of possible speed ranges and apply a different lead for each speed range. This strategy will be referred to as the Speed Categorization strategy. TRADOC Bulletin No. 5, Training with LAW, recommends this kind of strategy in using the U.S. Light Antitank Weapon. Specifically, the TRADOC bulletin recommends using only two target leads, one lead for fast targets and one for slow targets. Jones and Jehan (1978) also recommended categorizing target speeds. They recommended that gunners classify a target's speed as either slow or fast, and use a different lead for each speed category. If a simple display, such as that of the FCCS, allows gunners to place targets into one of two or more speed categories, training a Speed Categorization strategy should prove superior to training a single-lead strategy; a categorization strategy would cover a range of speeds much more effectively than a single lead.

A major empirical question with a Speed Categorization strategy concerns the number of categories into which the speed range should be divided.

Optimal performance requires that the number of lead categories equals the number of categories into which gunners can divide the speed range.

Considering this, the recommendation of only two categories by both TRADOC Bulletin No. 5 and the report by Jones and Jehan (1978) seems puzzling.

A massive amount of psychological and human factors research demonstrates that observers should be able to divide a sensory continuum into at least three categories, if not more (see Garner, 1962). In suggesting only two speed categories, the TRADOC bulletin references a U.S. Army Infantry Board report (1975) indicating that bracketing speed judgments into three categories is too difficult. However, the Infantry Board report considered targets moving about 15 mph or less. The restricted speed range considered may have been at least partially responsible for the conclusions.

Observers may have little difficulty dividing the broader speed range of the 1980's battlefield into at least three categories. As for Jones and Jehan, their recommendation of using two speed categories was based on subjective impressions of the difficulty of placing speed judgments into three categories, rather than on objective data. The current research was designed to empirically determine whether or not observers can accurately place moving targets into more than two categories.

The third, and most complex kind of lead strategy, involves calculation of the amount of lead needed based on the estimated speed of a moving target. Bessemer and Kraemer (1979) recommended such a strategy, which will be referred to as the Speed Magnitude Estimation strategy. Specifically, for APDS ammunition they recommended that gunners determine a target's speed to the nearest five miles per hour, divide this speed by ten miles per hour,

and multiply the result by 2.5 mils. For HEAT ammunition, a multiplier of 5 mils is required. Performance with this strategy would depend, of course, on how accurately observers could judge target speed to the nearest five miles per hour. If observers can accurately determine a target's speed to the nearest five mph in a simple display such as the FCCS, this strategy may be preferable for training; it would produce a high proportion of hits at any target speed. On the other hand, the complexity of the mental arithmetic required would severely tax the abilities of the average gunner, and the time required for the mental calculations may prohibit any such calculation strategy from being used by gunners in combat. If gunners can accurately judge target speed to the nearest 5 mph in the simulator, further research will be necessary to determine whether the complexity of this strategy makes it prohibitive for use in combat.

The kind of strategy most appropriate for training with simple displays, such as that of the FCCS, depends on observers' accuracy in judging target speed in the simulator. All three strategies require some kind of speed discrimination, but differ in the demands each places on the gunner's perceptual system. A Standard Lead strategy demands only that gunners be able to discriminate moving from stationary targets, a Speed Categorization strategy involving a small number of categories demands only that gunners make a few discriminations among broad categories, and a Speed Magnitude Estimation strategy demands that gunners be able to estimate target speed fairly accurately along a continuum. While the complexity of the discrimination increases from a Standard Lead to a Speed Magnitude Estimation strategy, the potential payoff in terms of target hits also increases, provided that gunners can make the perceptual discriminations each kind of strategy demands.

Unfortunately, psychological research has failed to yield pat answers to questions about observers' ability to judge the speed of targets. This failure is not due to poor quality or insufficient research, but reflects the relativistic operation of the human visual system. Brown (1931) demonstrated that the perceived speed of a target depends not only on its physical speed, but on the structure of the background against which the target is moving. To state the problem somewhat differently, several factors influence judgments of a target's speed; the apparent distance of the target, for example, exerts a major influence on its perceived speed (see Gogel and Tietz, 1974; Gogel, 1977; Epstein, 1978). The apparent distance of a target in turn, depends on certain cues, or characteristics of the scene in which the target appears. The cues to distance incorporated into a simulator's display will therefore influence judgments of target speed, and could be expected to reduce transfer of lead training if target speed is systematically misperceived.

As can be seen from the above discussion, the current research investigated the adequacy of the perceptual information provided by the FCCS display. That is, the current research assessed observers' ability to judge target ranges, distances along the ground, and the slant of the ground as represented by the display. The purpose of collecting these data was to determine the kind of impression of three-dimensional space provided by the display, and to determine whether the pattern of errors in spatial judgments differed markedly from errors in spatial judgments in the field.

Since no trainer can be assessed independently of the way it is to be used, a different facet of the question about the adequacy of the FCCS

display involves its adequacy with respect to the kind of gunnery technique trained with it. In the current research, three different strategies for leading moving targets were assessed by examining the ability of observers to determine target speed when different kinds of speed judgments must be made. Because of the minimal demands of a single Standard Lead strategy, the experimenters did not collect empirical data on how well observers could discriminate stationary from moving targets, but concentrated on the kind of speed discriminations demanded by the other two strategies. The kind of speed judgments observers are able to make will determine the kind of lead strategy that is most appropriate for training using a simulator with a simplified display, such as the FCCS. The current report concludes with a logical analysis of the use of lead strategies in the field, and makes recommendations for further research, to determine whether a lead strategy that can be taught in the simulator is effective in the field.

METHOD

Subjects. 28 trainees (25 gunners and 3 drivers) in the One Station Unit Training (OSUT) course at Ft Knox served as observers. Troops were assigned to two groups of 14 subjects each. One group consisted of 13 gunners and one driver; the other consisted of 12 gunners and two drivers. Group assignment was counter-balanced based on the order in which observers came to the experiment. On the first day the first observer was assigned to the Speed Categorization group, and the second was assigned to the Speed Magnitude Estimation group; on the second day the first observer was assigned to the Speed Magnitude Estimation group, and the second was assigned to the Speed Categorization group, etc.

Apparatus. The Chrysler FCCS (Fire Control Combat Simulator), shown in Figure 2, consists of an instructor's console and a gunner's station. Chrysler Corporation describes the instructor's console and gunner's station, respectively, as follows:

"This console provides power control, self-test, program direction and engagement start/stop commands. Two visual displays are provided by the console. A display monitor . . . provides a visual assessment of the gunner's proficiency in . . . tracking and firing. A printer provides a permanent record of the gunner's performance . . ."

"An eyepiece allows the gunner to view the action area as if viewing through the tank. The gunner can observe terrain, target and aiming reticle. Through handle inputs, the gunner can move the field of view (FOV) to acquire, . . . track, lead, and fire on a target."

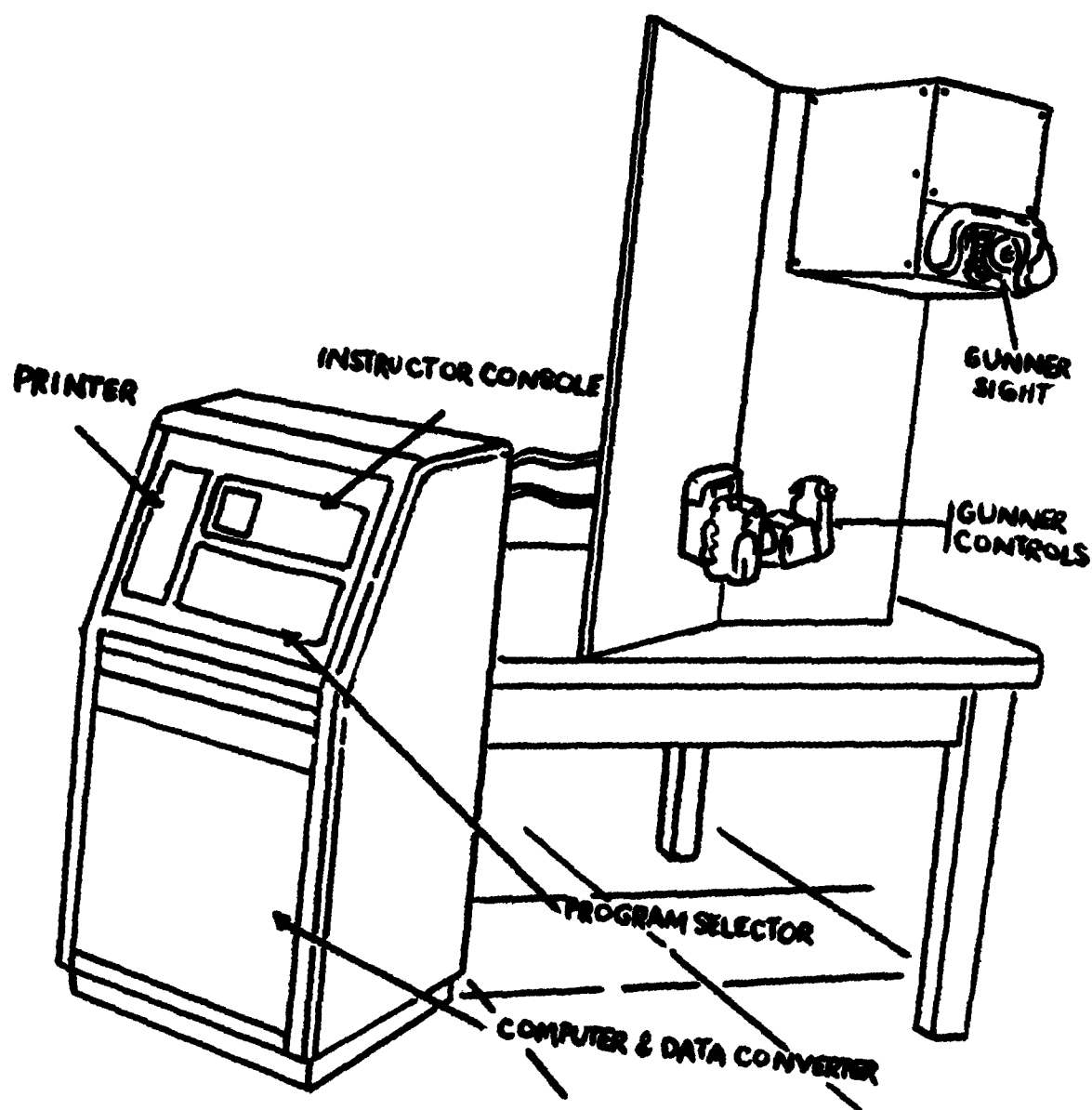


Figure 2. The Chrysler FCCS

The FCCS presented trainees with visual displays of a moving, rectangular target. The simulator was programmed to present the moving target at a simulated speed of either 10, 15, or 25 mph. Observers viewed displays (see Figure 1) through an eyepiece like that of the primary sight in an M60A1 tank. The experimenter timed the duration of the visual displays with a hand-held stopwatch. Observers matched the perceived slant of the display's "ground" from the horizontal with a slant board approximately 8 inches long, hinged to a large horizontal base. The adjustable angle between the slant board and the base was measured by a protractor.

Procedure. Each observer was tested individually. Observers sat in front of the simulator's gunner controls and adjusted the sight's focus while viewing the FCCS display of a stationary head-on target at a range of 1500 meters. The observer then received the instructions provided under heading 2 of the data sheet in Appendix A. The experimenter centered the reticle cross on the target and instructed the observer to operate the controls and scan the display until he had seen the entire grid pattern forming the display "ground." The experimenter then centered the crosshairs on the target and asked the observer to report the width of the grid representing the ground (to the nearest 50 yards or 50 meters, whichever the observer preferred) at: (1) the edge nearest the observer (2) the edge farthest from the observer, and (3) an intermediate distance. The observer was then asked to estimate the length of the grid (again, to the nearest 50 yards or 50 meters). Before the observer responded, the experimenter moved the crosshairs over the distance to be judged in order to avoid confusion and refresh the observer's memory. Each observer was

then asked to adjust the angle of the slant board until it matched the slant of the ground in the display. Finally, each observer judged the range of the target (again, to the nearest 50 yards or 50 meters) at 1000 meters, 1500 meters, and 2500 meters.

The experimenter told each observer that he would see some displays of moving, tank-sized targets and that his task was to judge each target's speed. Each of the two experimental groups received different specific instructions about judging target speed. Page 2 of the sample data sheet in Appendix A contains the specific instructions. The experimenter informed the Speed Categorization group that the targets would move across their field of view at either a slow, medium, or fast speed at various distances from them, and that they were simply to say on each trial whether the speed of the target was slow, medium, or fast. The experimenter told the Speed Magnitude Estimation group that the targets would move across the screen at different speeds and at different distances from them, and that on each trial they were to report to the nearest 5 mph how fast the target was moving.

At the beginning of each trial, the experimenter instructed the observers in both groups to look away from the eyepiece, and not to look into it until the experimenter said "go." The experimenter initiated the display and adjusted the reticle crosshairs so the horizontal line of the crosshairs was even with the bottom of the target, and the vertical line of the crosshairs was centered horizontally on the grid. When the target moved to the center of the grid, the experimenter said "go" and began timing the display, as the observer looked into the sight. After approximately

five seconds, the display went off and the observer reported the target speed according to the instructions for his group. The experimenter recorded the observer's response and initiated the next trial. Because the target moved at different speeds, and therefore took different times to reach the center of the grid, the inter-trial interval was varied independently of the target speed. This prevented differences in inter-trial interval from serving as a cue to target speed.

Each observer judged target speed in four blocks of 18 trials each. Each block of 18 trials consisted of targets at one of three different ranges (1000, 1500, or 2500 meters), moving at one of three different simulated speeds (10, 15, or 25 miles per hour), and moving one of two different directions (left or right). Each possible combination of these variables occurred only once in a random sequence during each block.

During the first two blocks of 18 trials, observers received no information about the target range. During the second two blocks, the experimenter told observers the target's range before each trial to determine whether range information produced a sharp improvement in velocity judgments beyond practice effects accruing over successive blocks.

After all four blocks of trials, observers repeated the distance and slant judgments of the display just as at the beginning of the session. Page 5 of Appendix A indicates the exact procedure followed.

RESULTS AND DISCUSSION

Distance and Slant Judgments. Figure 3A shows \pm one standard deviation about the mean width judgment of the display grid, calculated over all observers' data. The dotted line indicates the correct width of the display (1500 m). On the average, observers slightly underestimated the display's width before being told the ranges at which the target appeared, and slightly overestimated the width after receiving range information. However, because of the extreme inter-observer variability, as reflected by the standard deviations in Figure 3A, little emphasis should be placed on these averages.

Figure 3B shows observers' estimates of the slant of the grid. Large inter-observer variability also characterized slant responses, consistent with past research on slant perception (Stavrianos, 1945). In addition to being highly variable, observers overestimated the 5° slant of the ground over which the target moved by almost 300% on the average! That is, they estimated that the grid representing the ground in the display deviated much more from the horizontal plane than it actually did. This result also agrees with past research on slant perception (see Gibson, Gibson, Smith, and Flock, 1957).

Observers' estimates of the length of the grid (shown in Figure 3C) and range estimates (shown in Figure 4) also reveal large intersubject variability. The large amount of variability in these data is consistent with that found in a good deal of past research on space perception (see, for example, Stark, Wolff, and Haggard, 1961; Johansson, 1973; Eriksson, 1974). Observers' judgments initially showed large deviations from the

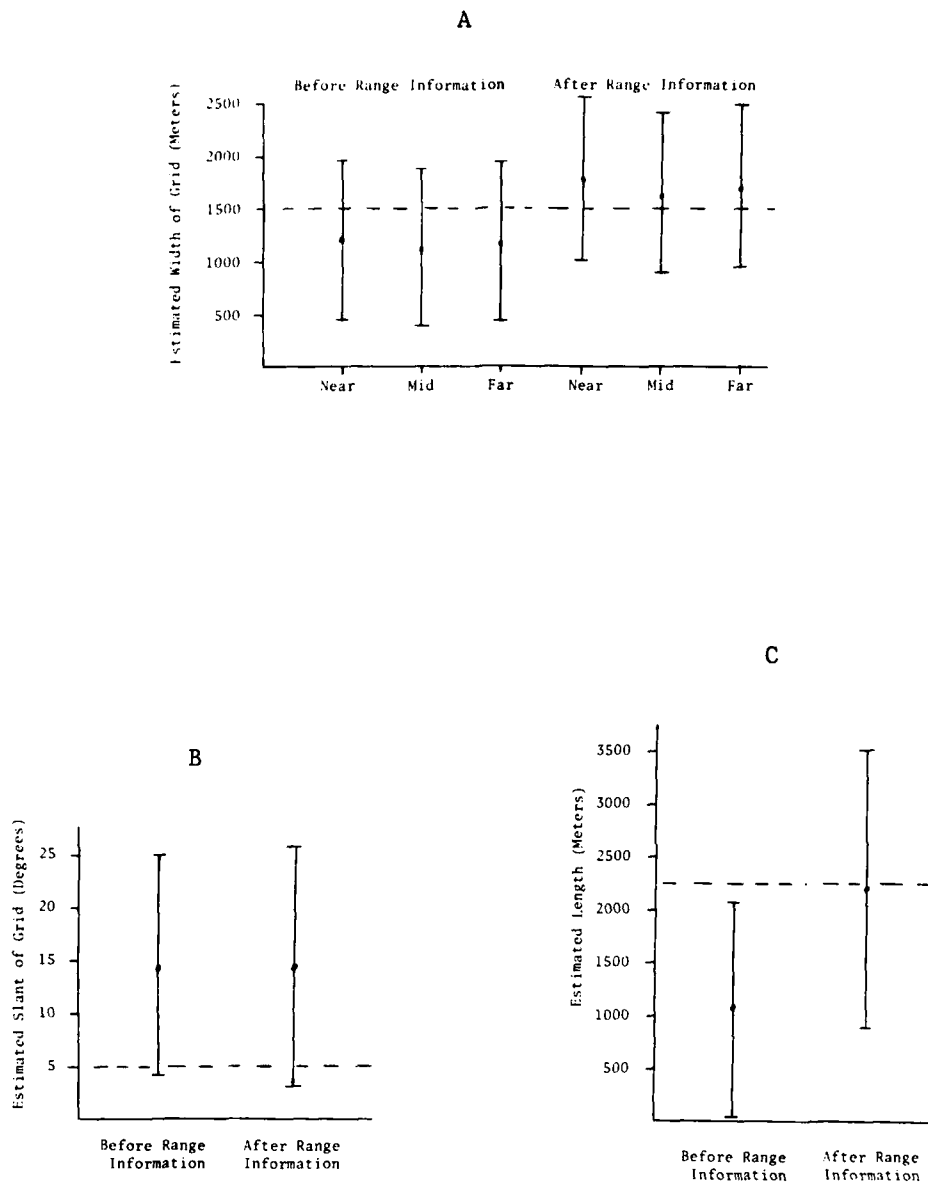


Figure 3. Width, Slant, and Length Estimates of FCCS Grid.

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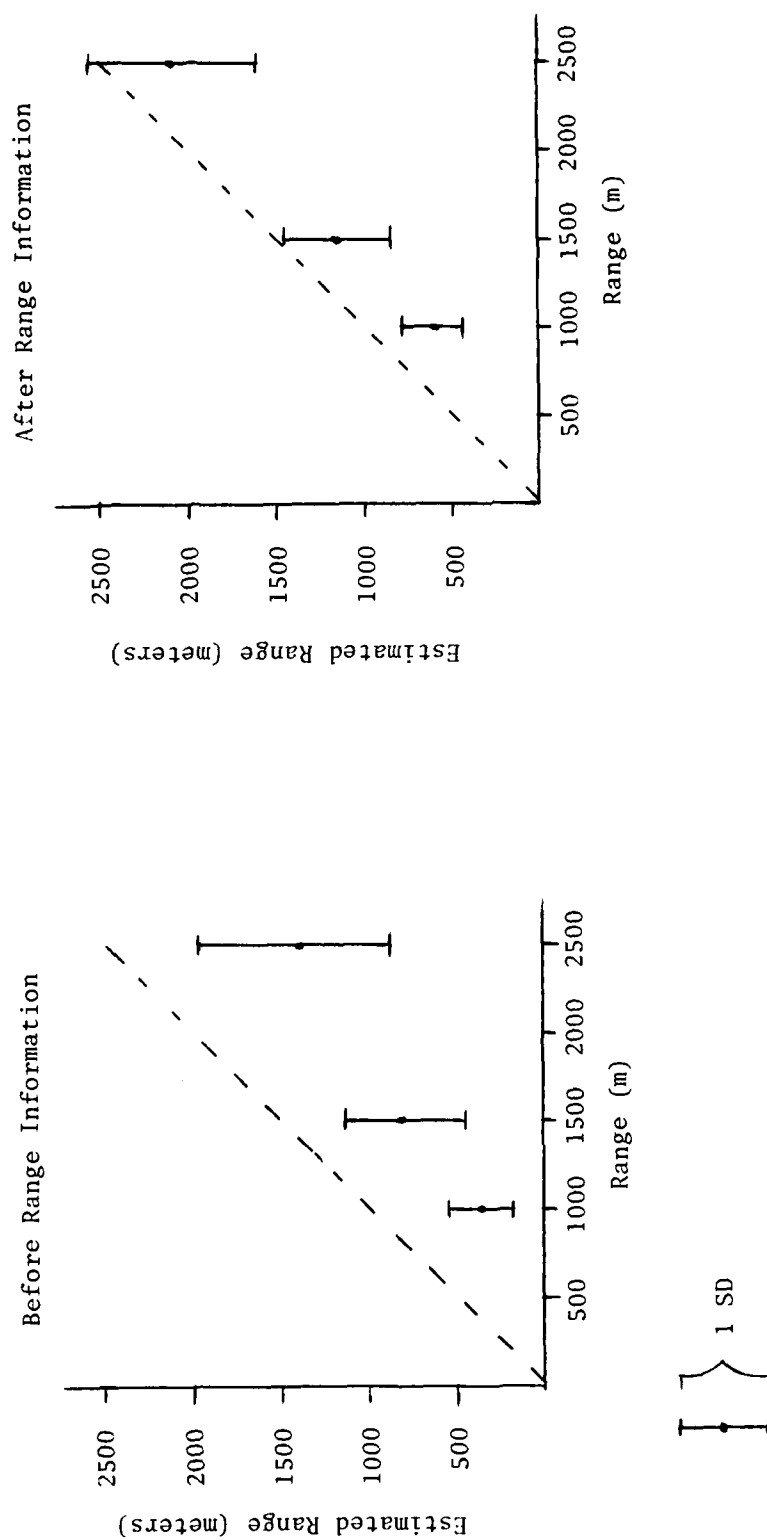


Figure 4. Range Estimates on Chrysler FCCS.

values represented in the display. Before observers received any range information, the length of the grid was grossly underestimated; average estimates were somewhat less than 50% of the actual length. The accuracy of observer's length estimates increased after they received range information, as can be seen in Figure 3C. The tendency to systematically underestimate distance in the display persisted for judgments of target range, and continued even after observers were told the ranges at which the target appeared, as can be seen in Figure 4.

This tendency to underestimate distance (that is, for observers to say that the target was closer than it should have appeared in the simulator) agrees with results of research on distance estimates in the field. For example, Gibson, Bergman, and Purdy's (1955) untrained observers significantly underestimated target range. Examination of Stark, Wolff, and Haggard's (1961) data shows that, over all groups, their observers tended to underestimate target range, and that this tendency was marked at ranges beyond 1,000 meters. Range underestimation also has been demonstrated for aerial targets; Wright (1966) found that observers using unaided vision consistently underestimated target ranges of less than 10,000 meters.

If the systematic range and distance underestimates in the FCCS had not agreed with results from the field experiments cited above, one might have attributed the errors and the large variability obtained in the present research entirely to insufficient depth cues contained in the FCCS display. Since the pattern of results obtained does not differ markedly from that of some field research, it is not clear that adding depth cues to the FCCS display would improve observers' distance or slant judgments. Adding

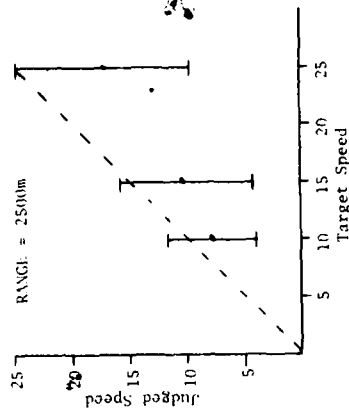
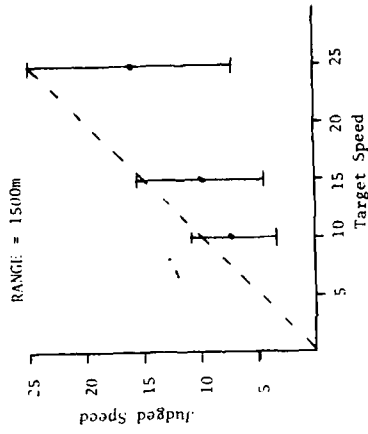
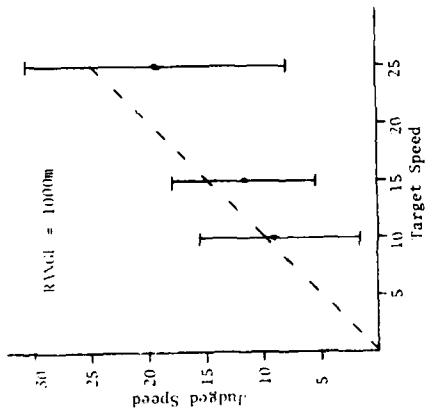
further depth cues to displays intended for moving target gunnery training may not be cost effective.

The present study, however, does not justify any decision on the display complexity required in a conduct-of-fire training simulator. The adequacy of a simplified display for transfer of lead strategies remains to be investigated. Furthermore, other aspects of gunnery performance, such as battlesight technique, firing on-the-move, or fire adjustment may require much more realistic depth cues or a higher level of detail. Decisions on display complexity should be based on an assessment of requirements for effective training and transfer of all gunnery skill components.

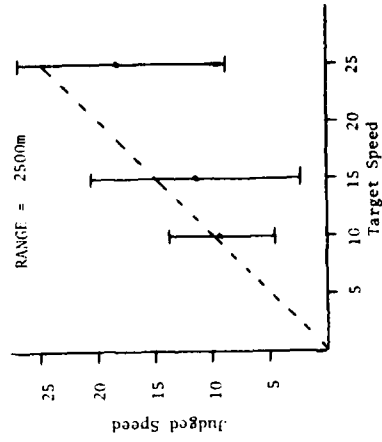
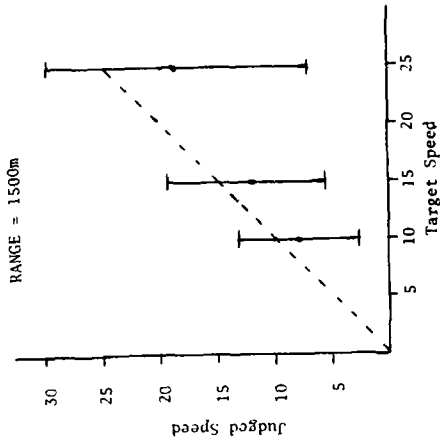
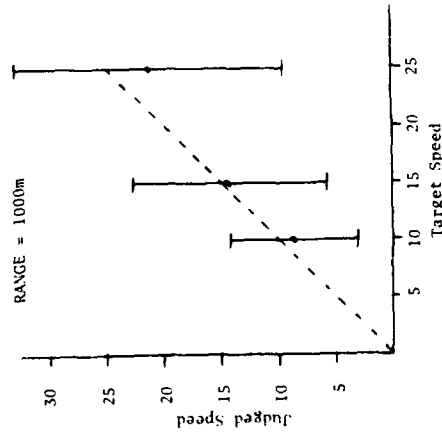
Speed Judgments. Speed judgments by the Speed Magnitude Estimation group showed large inter-observer variability, and remained variable over all four blocks of trials. Figures 5 and 6 show the speed judgment data. The dotted diagonals in these figures indicate perfect performance. Before observers received range information, they consistently underestimated target speed, but improved after they received range information. However, the extreme inter-observer variability discourages much discussion based on average performance. The large amount of variability in speed judgments agrees with that found at Haglund and Torre (1978).

Observers in the Speed Categorization group identified target speed as either fast, medium, or slow quite well. Table 1 shows the proportion of correct identifications for each speed. It is clear from Table 1 that the greatest proportions of confusions occurred between the slow and medium speed groups. Since the difference between the slow and medium target speeds was so small (5 mph), this was to be expected.

BLOCK 1

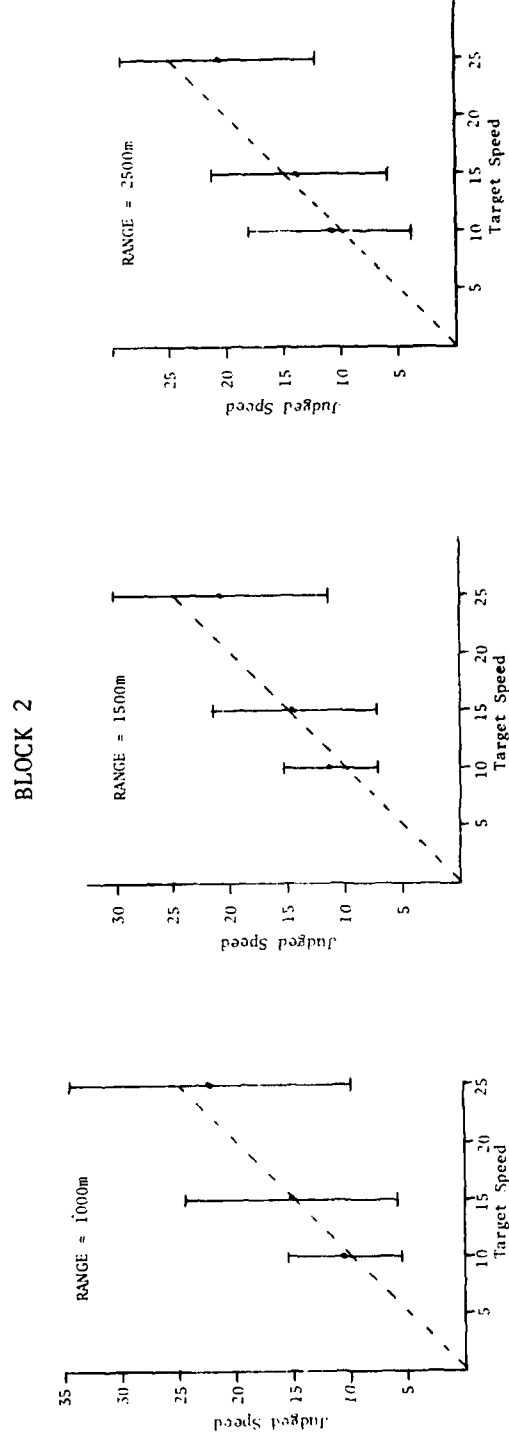
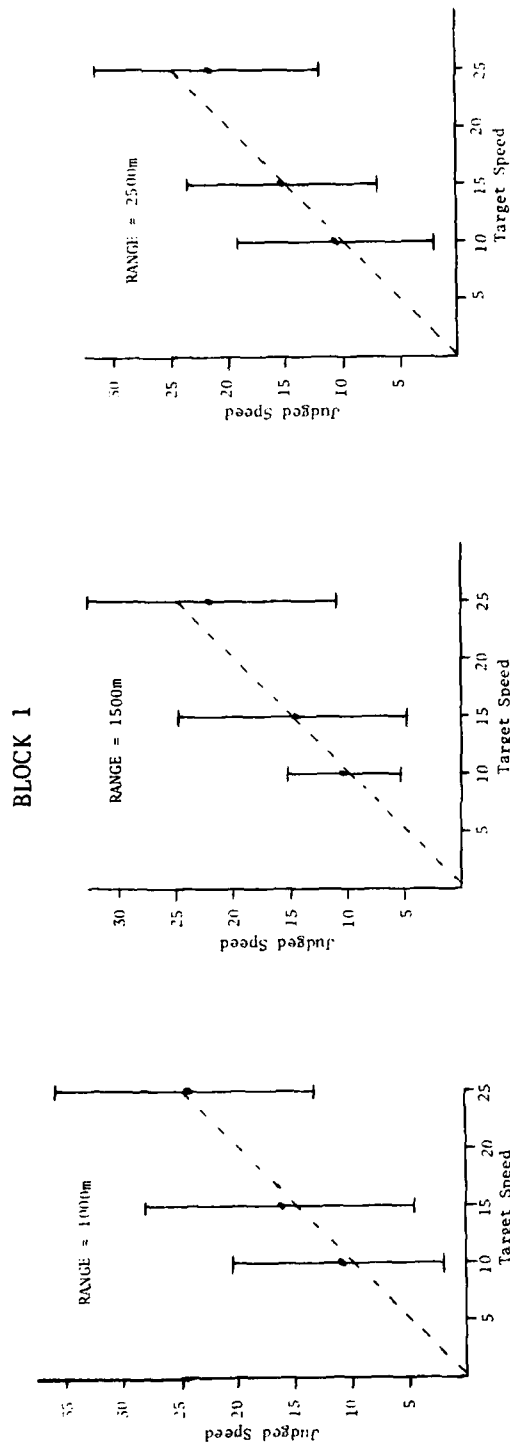


BLOCK 2



$\pm 1 \text{ SD}$

Figure 5. Speed Judgments. No Range Information.



$\pm 1 SD$

Figure 6. Speed Judgments. Range Information.

TABLE 1

Proportion of Correct Identifications in Each Speed Categorization Group

| ACTUAL TARGET SPEED | PROPORTION OF SLOW (10 mph) | RESPONSES IN MEDIUM (15 mph) | EACH CATEGORY FAST (25 mph) | OVERALL PROPORTION CORRECT |
|--------------------------------------|-----------------------------------|------------------------------------|-----------------------------------|----------------------------------|
| Block 1 (No Range Information) | | | | |
| 10 mph | *.714 | .238 | .048 | .710 |
| 15 mph | .250 | *.619 | .131 | |
| 25 mph | .012 | .190 | *.798 | |
| Block 2 (No Range Information) | | | | |
| 10 mph | *.750 | .250 | .000 | .817 |
| 15 mph | .167 | *.798 | .035 | |
| 25 mph | .000 | .095 | *.905 | |
| Block 3 (Range Information) | | | | |
| 10 mph | *.702 | .274 | .024 | .774 |
| 15 mph | .155 | *.738 | .107 | |
| 25 mph | .012 | .107 | *.881 | |
| Block 4 (Range Information) | | | | |
| 10 mph | *.798 | .202 | .000 | .849 |
| 15 mph | .131 | *.833 | .036 | |
| 25 mph | .000 | .083 | *.917 | |

*Indicates correct identifications.

One cannot directly compare performance of the two groups, since the kind of judgments made by observers in the two groups were different. However, one can compare the performance of the two groups indirectly by using their speed judgments as input parameters to a model of tank gunnery. Inputting different speed judgment parameters allows calculation of predicted hit probabilities for different kinds of lead strategies.

Description of the Tank Gunnery Model. Converting speed judgment data to expected hit probabilities first required the calculation of hit probabilities for various amounts of lead when applied to different speed targets. These calculations were made for a model of tank gunnery incorporating the characteristics of the FCCS and making the following assumptions:

- 1) A normal distribution of rounds about the lay point, having a standard deviation of .32 mil horizontal and .28 mil vertical (from Pfleger and Bibbero, 1969).
- 2) Normally distributed vertical lay errors, having a standard deviation of .1 mil (also from Pfleger and Bibbero, 1969).
- 3) Normally distributed horizontal tracking errors, having a standard deviation of 1.0 mil (estimated from errors on a tracking task in research by Obermayer, Swartz, and Muckler, 1961).¹

¹The tracking errors reported were converted to mils and the standard deviation of that distribution was doubled since Obermayer, Swartz, and Muckler used a well-defined tracking point in contrast to the absence of such a point when tracking a moving target and applying lead with the M60A1 reticle. Although 1 mil was used as an error of tracking performance with the device, some evidence suggests that tracking error, and even vertical lay error, would be much larger for camouflaged targets actively using cover and concealment (see Garry, 1974).

4) Error factors such as zeroing errors, wind, temperature, coriolis effects, etc., were negligible.

Speed Judgment Data Applied to a Model of Tank Gunnery in the FCCS.

Predicted hit probabilities for the Chrysler FCCS firing APDS were calculated for four different hypothetical lead strategies: (1) a strategy in which the gunner applies a single standard lead of 2.5 mils regardless of target speed, (2) a lead calculation strategy in which the gunner estimates target speed to the nearest 5 mph, and leads the target by 2.5 mils for every 10 mph of target speed, as suggested by Bessemer and Kraemer (1979), (3) a lead calculation strategy in which the gunner estimates target speed to the nearest 5 mph, and leads the target by 3.5 mils for every 10 mph of target speed, to optimally compensate for the tendency to underestimate target speed, and (4) a 3-lead strategy in which the gunner judges the target's speed to be either slow, medium, or fast and applies a 2.5, 5.0, or 7.5 mil lead, respectively. The method for calculating estimated hit probabilities is described in detail in Appendix B. In examining the estimated hit probabilities, two points should be kept in mind. First, the hit probabilities predicted using the model apply only to the device and would be much lower overall in any field tests of lead strategies; live firing would involve error factors that were not incorporated into the model for the sake of simplicity. Second, no data were actually collected on the application of leads to moving targets. Hit probabilities were determined by applying speed judgment parameters to the model while assuming a relationship between judged speed and applied lead that would be appropriate for a given lead strategy. That is, the predicted hit probabilities

were derived under the assumption that a given lead strategy would be exactly and accurately adhered to.

Predictions of hit probabilities were not made for a strategy requiring gunners to classify target speed into one of two categories. The data collected in this research do not allow statements about how accurately observers can segregate target speeds into two broad categories. Furthermore, if gunners accurately segregate target speeds into three categories, a two-category strategy does not take full advantage of their perceptual capabilities.

Figure 7 shows the calculated hit probabilities for the four hypothetical lead strategies as a function of target range, combined over the three target speeds used in this research. Figure 7 also shows optimal performance as limited by the error factors considered in the model, and optimal performance using the strategy suggested by Bessemer and Kraemer (1979), given speed judgments that are always correct to the nearest 5 mph. According to the predictions of the model, the 3-lead categorization strategy will produce approximately 20% more hits than the next best alternative over all three ranges. Furthermore, the model predicts that performance using the 3-lead strategy will be roughly equivalent to the best performance possible when using the strategy of estimating target speed to the nearest 5 mph and calculating lead using the formula suggested by Bessemer and Kraemer. As Figure 7 shows, predicted performance using the 3-lead strategy approaches optimal performance within the limits imposed by the error terms incorporated into the model.

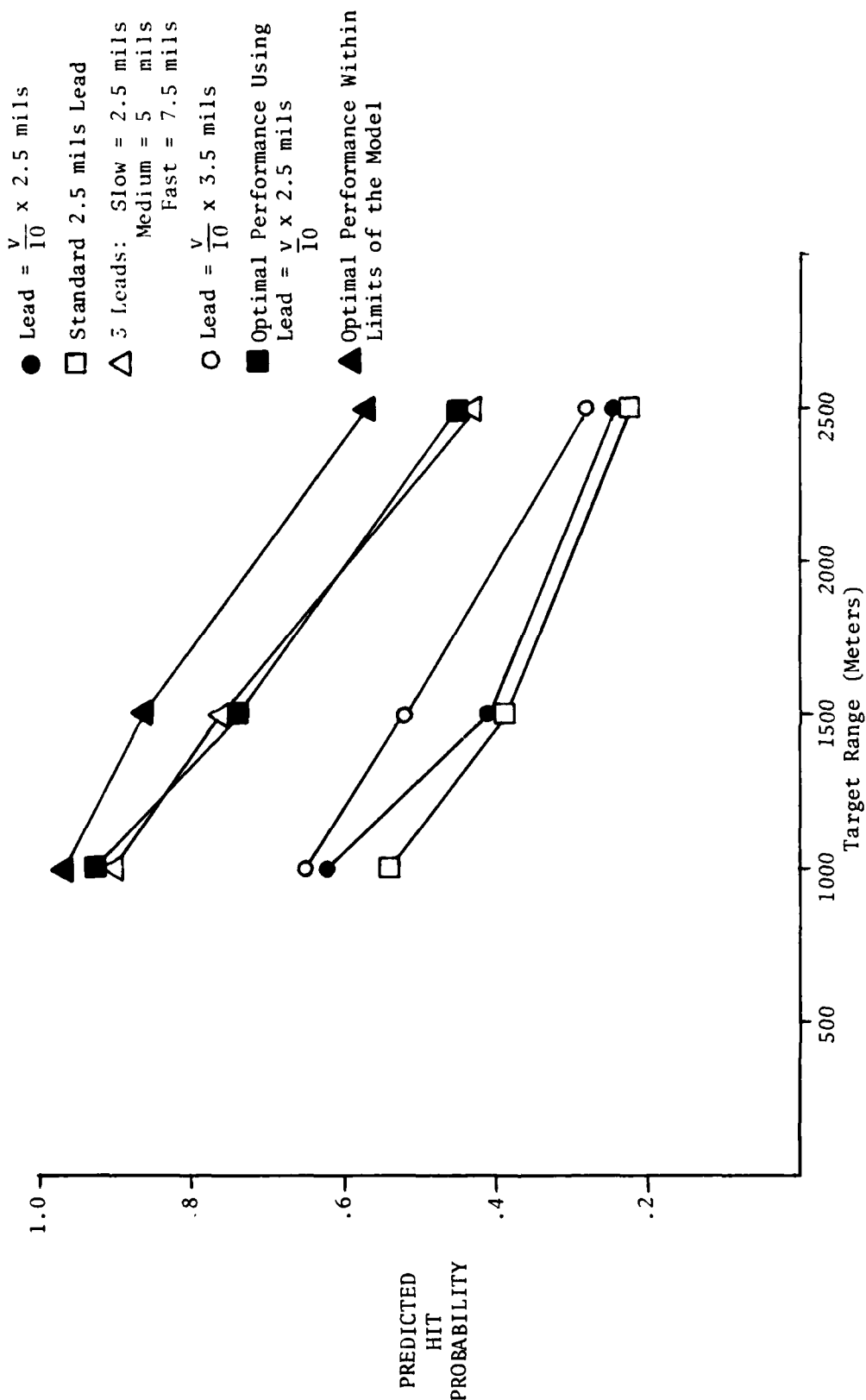


Figure 7. Predicted Hit Probabilities for Four Different Lead Strategies and Optimal Performance Within the Limits of the Model, as a Function of Target Range. Tank Firing APDS at a 2.5 x 5 Meter Flank Target. Parameters Estimated From Data Collapsed Over All Three Speeds and Over All Practice Blocks.

Figure 8 conveys a different aspect of performance; it shows predicted hit probabilities as a function of target speed, with predictions collapsed over all three target ranges. The prediction for the standard 2.5 mil lead is superior to the other strategies for targets moving approximately 10 mph, since there would be almost no variance and little error in applying the standard lead at this speed. However, the rapid drop in predicted performance for this strategy with increasing target speed, and the low probability that targets will move only 10 mph on the modern battlefield make it an undesirable strategy. Over all speeds, the model predicts that the 3-lead strategy will produce over 20% more hits than the next best alternative. Again, the prediction for the 3-lead strategy is close to optimal performance.

Figure 9 illustrates an additional advantage of the 3-lead strategy; the model predicts higher hit probabilities for the 3-lead strategy initially, and shows that this superiority should continue over practice. Observers in this research did not improve substantially in estimating speed over the course of the experiment. It might take extremely long for gunners to learn to estimate speeds well enough so that other lead strategies would even approach the performance expected from using the 3-lead strategy, if they could even do so. Recall that nearly perfect judgments of speed would be required using a lead calculation strategy such as that proposed by Bessemer and Kraemer (1979) in order to match performance with the 3-lead strategy.

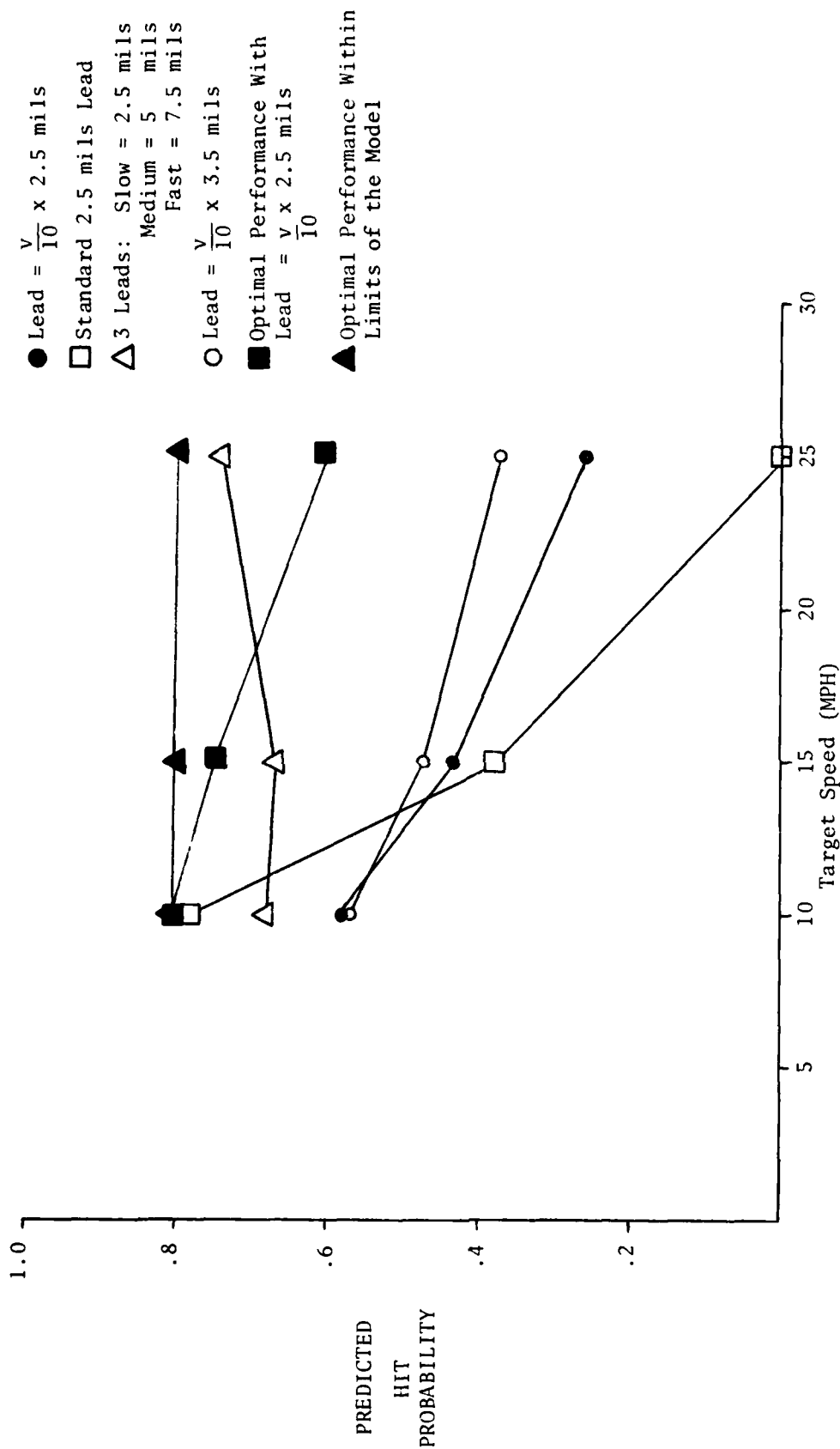


Figure 8. Predicted Hit Probabilities for Four Different Lead Strategies and Optimal Performance Within the Limits of the Model, as a Function of Target Speed. Tank Firing APDS at a 2.5 x 5 Meter Flank Target. Data Collapsed over Ranges and Practice Blocks.

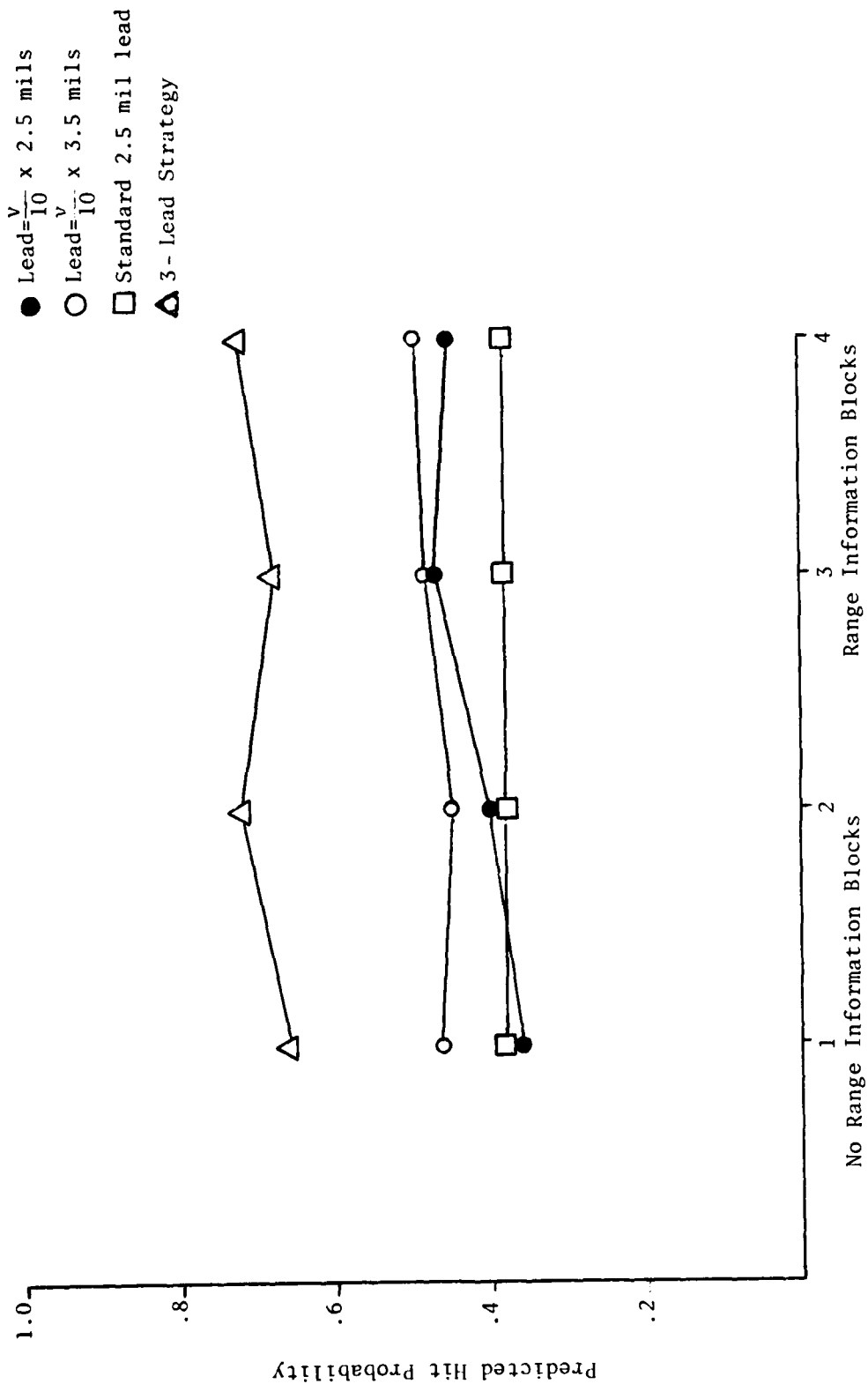


Figure 9. Predicted Hit Probabilities for Four Different Lead Strategies Over Successive Blocks of Eighteen Engagements. Chrysler FCCS Firing APDS at a 2.5x5 Meter Flank Target. Data Collapsed Over Three Target Ranges and Three Target Speeds.

Some readers might object to the conclusion that performance using the 3-lead strategy would prove superior to performance using any of the other lead strategies, since the parameters input to the model are based on data from judgments on only three target speeds. One might be concerned about the predicted hit probabilities for targets moving at speeds other than 10, 15, and 25 mph. To address this concern, the predicted hit probabilities were calculated for a target moving at 5 and at 20 mph for all three strategies.

Hit probabilities for the lead calculation strategy proposed by Bessemer and Kraemer were calculated by first obtaining estimated means and standard deviations of the distribution of speed magnitude judgments at 5 and 20 mph. The means and standard deviations at these speeds were estimated from regression lines fit to the means and standard deviations of speed judgments for 10, 15, and 25 mph target speeds. The regression equations were calculated separately for means and for standard deviations at each of the three target ranges--resulting in six separate regression equations. Since there were only three points on which to base each regression equation, the regression lines were forced through the origin based on the reasonable assumption that stationary targets would always be perceived as stationary so that resulting speed judgments would have both a mean and standard deviation of zero. Even with this restriction, the regression equations for the mean speed judgments accounted for approximately 98% of the variance at all three ranges. The regression equations for the standard deviations fared almost as well; each accounted for at least 94% of the variance. Predicted

hit probabilities were then calculated for target leads based on the estimated distributions of speed judgments, as described earlier.

Hit probabilities for the 3-lead strategy were calculated by first estimating the proportion of slow, medium, and fast categorizations of targets at each of the two speeds. The proportion of "slow" (i.e., 10 mph) categorizations of a 20 mph target was estimated by the average proportion of categorizations of fast speed targets (25 mph) as medium speed targets (15 mph) observed over all four blocks of trials.² The remaining proportion of responses was assumed to be equally divided between "medium" and "fast" categorizations. The proportion of categorizations of the 5 mph target as "fast" was conservatively estimated by the proportion of categorizations of slow speed (10 mph) targets as "fast" observed over all four blocks of trials. The proportion of categorizations of 5 mph targets as "medium" (i.e., 15 mph) was estimated from the average proportion of observed categorization of medium speed targets as "fast" -- also a difference of 10 mph.³ The remaining proportion of categorizations was "slow."

The results of the estimated hit probabilities for targets moving from 5 to 25 mph are shown in Figure 10. One can see that although the hit probability for the 3-lead strategy drops at target speeds of 20 mph, it still

²This figure was used to estimate misidentification of a 20 mph target as slow (10 mph) since it reflects confusions of two target speeds that were also 10 mph apart. It should be a conservative estimate, since Weber's law predicts that a given difference between two stimuli that have low values on a scale should be more detectable than the same difference between two stimuli that have high values on an equal interval scale.

³This estimate should be very conservative, for the same reason as that given in footnote 2.

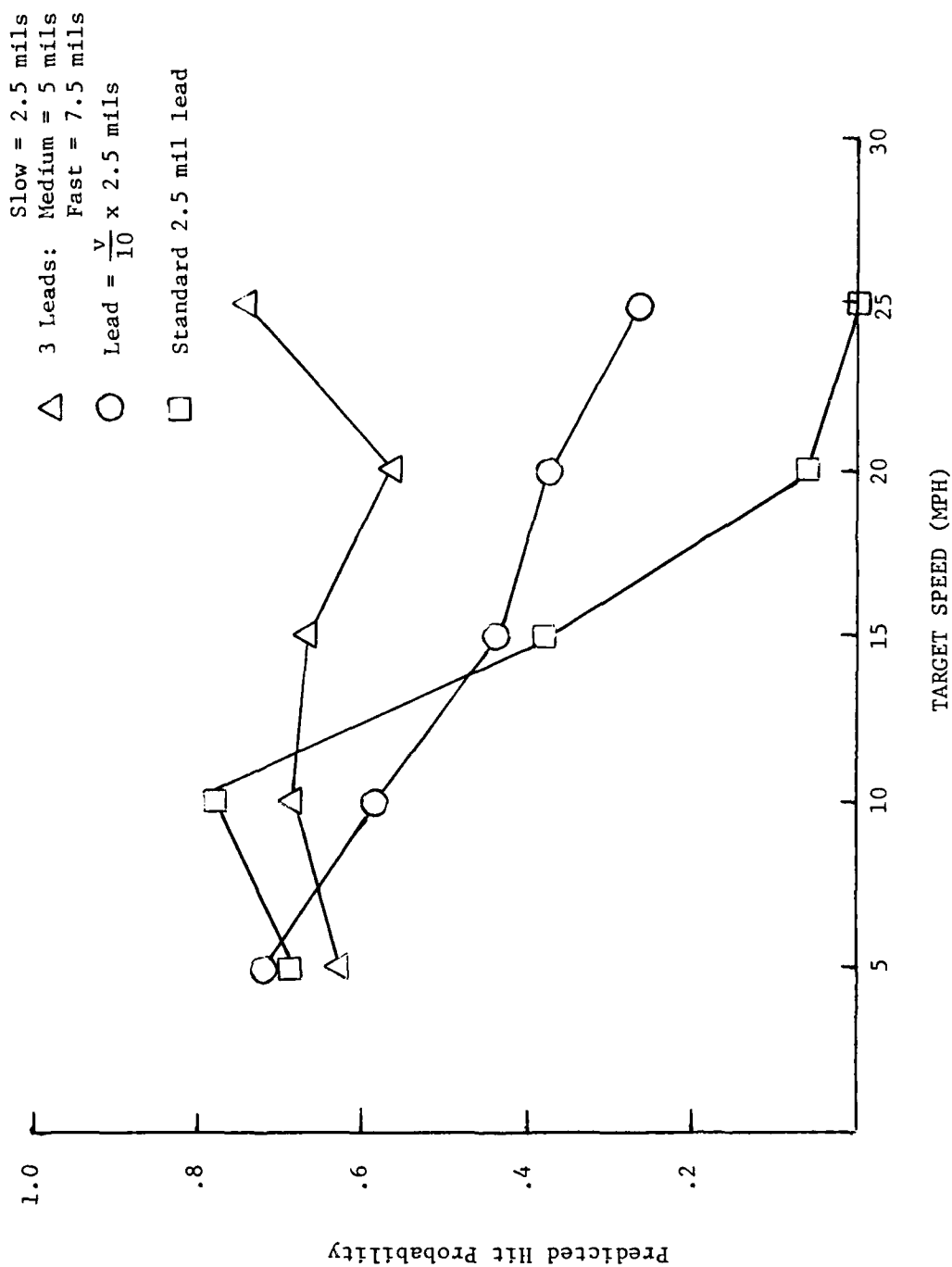


Figure 10. Predicted Hit Probabilities over a Range of Target Speeds.
 Tank Firing APDS at a 2.5 x 5 Meter Flank Target.

stays well above that predicted for the strategy of calculating lead based on an estimate of target speed in miles per hour. The strategy proposed by Bessemer and Kraemer proves to be superior to a 3-lead strategy only for very slow target speeds, as can be seen by the estimated hit probabilities on a 5 mph target. The poor hit probability using the standard 2.5 mil lead at target speeds of 15 mph and faster make it unacceptable.

Comparison of the lead calculation and 3-lead strategies on a 5 mph target clearly brings home the point that overall, estimating target speed in miles per hour produces poor performance because of observers' variability in estimating target speed. At extremely slow speeds, this variability in speed judgments is reduced, partly because the lower limit on responses (0 mph) is so close to the actual speed (i.e., there is a basement effect) and partly because in the current research the variability of speed judgments was directly related to the mean.

The reason for the difference in performance between the two speed estimation groups probably reflects the combined operation of two different phenomena. First, the difference almost certainly reflects the operation of an uncertainty effect. Recall that the Speed Categorization group could make only one of three responses -- slow, medium, or fast. The Speed Magnitude Estimation group, on the other hand, could make any one of 11 different responses between 0 and 50 mph inclusive; they were more uncertain about the stimulus that would occur (and hence which response they should make) and tended to use a broader range of the responses available than was warranted by the stimuli. This tendency is reflected by the fact that the

Speed Magnitude Estimation group assigned an average of slightly over 4.1 different speeds to targets in each block of trials, even though only three different target speeds were presented. The uncertainty effect operated by producing highly variable responses within the responses of individuals in the Speed Magnitude Estimation group. Limiting the number of allowable responses to three for the Speed Categorization group avoided the large variability by restricting the fineness with which observers attempted to make the speed discriminations.

Second, the difference in performance of the two groups reflects the perceptual system's facility in processing relative information and inaccuracy in processing absolute information (see Gogel, 1977; Kottas, 1978). A major problem in making absolute judgments seems to be one of calibrating responses correctly, provided that the cues for ordering stimuli are available. Expressing speed judgment performance in terms of hit probabilities makes it clear that a categorization strategy would be the most effective for training gunners using simplified displays, as in the FCCS.

While the results indicate that training gunners to discriminate target speeds within three broad categories will provide more effective performance than attempting to train them to estimate target speed to the nearest 5 mph in the simulator, the results are not definitive for application in the field. The simulated targets in this research only moved at one of three different speeds; different results may be obtained when targets are allowed to move at speeds other than 10, 15, and 25 mph, or are allowed to move at any speed. Increasing or decreasing the number of

categories into which observers must classify target speeds may influence the accuracy of their judgments, and affect transfer to field conditions. While fewer discrimination categories should lead to fewer confusions among categories, reducing the number of categories would reduce the number of leads used and would lead to less efficient coverage of the entire continuum of target speed. Using more leads would cover the speed continuum more effectively, but increasing the number of speed judgment categories should produce more confusions among categories (see Lappin and Uttal, 1976).

Despite these questions, a categorization strategy has certain intuitive advantages over either a single-lead, or lead calculation strategy, all of which required empirical test. First, requiring trainees to learn one lead for each of several target speed categories seems more reasonable than attempting to teach trainees formulas that they must use under extreme stress to calculate the amount of lead needed. Second, because of the stress and time constraints during combat, speed judgments overall are likely to be worse than those obtained during research, and may render a Speed Magnitude Estimation strategy totally ineffective. Third, the reticle markings on the M60A1 provide easy references for a few lead categories (2-1/2, 5, and 7-1/2 mils for APDS, 5, 10, and 15 mils for HEAT). Trainees will certainly experience difficulty in attempting to lead targets at other than these well-defined marks; more tracking error will be introduced when intermediate reference points are used, as would occur often for a lead calculation strategy. Fourth, allowing gunners to use only a few memorized leads should be much faster than requiring them

to calculate leads. Fifth, a speed categorization strategy has a much higher first round hit probability than a single-lead strategy. A single-lead strategy rests heavily on the ability of gunners to adjust fire using techniques such as Burst-on-Target (BOT) to achieve a second round hit. In order for BOT against a moving target to be optimally effective, the first round must be sensed accurately, and the target must not change speed or direction, stop momentarily or become obscured after the first round impacts. On the modern battlefield, these conditions may not always be met. Furthermore, most sources indicate that applying BOT results in a 25% increase in second round hit probability, at best (see, for example, Hannig, 1979). If one refers to Figures 7 and 8 again, it is clear that averaged over all target speeds and ranges, the hit probability obtained using the standard lead on the first round and BOT on the second still fails to reach the first round hit probability predicted for a categorization strategy.

Although a categorization strategy of some kind should be very effective, the number of speed categories that will provide optimal performance against targets moving at speeds representative of the 1980's battlefield remains to be determined through empirical research. Four speed categories (i.e., 10, 20, 30, and 40 mph) may be optimal for use against modern threat armored vehicles, but this remains to be tested empirically. It is also important to stress that the optimal number of speed categories for applying lead is not simply the number of categories that observers can discriminate perfectly. Discriminating two categories perfectly, for example, would

probably not be as effective as discriminating among more categories with some small amount of error. On the other hand, the time required to fire the first round is also a factor to be considered in determining the number of categories to be used. As the number of categories increases, one would expect longer times to elapse before firing the first round. An overwhelming amount of psychological literature demonstrates a tradeoff between reaction time and the number of alternatives to be discriminated (for example, see Sternberg, 1966). Both the value of various lead strategies with respect to speed-accuracy tradeoff and the utility of Speed Categorization strategy demand careful empirical research and field validation.

Although a categorization strategy has certain intuitive appeals, it cannot be overemphasized that empirical research must be done in the field before suggestions are made to install it in the Army's gunnery training. A complete test would require pitting a categorization strategy against other strategies in a live firing exercise with variable-speed targets.

Finally, we must stress that this research does not demonstrate training effectiveness of the FCCS. Gunnery training with evasive targets, training of battlesight techniques, training of fire adjustment techniques, and other important gunnery skills have not been addressed in this research. Validation of the training capability required by a general purpose conduct of fire trainer demands further research, both in the laboratory and in the field.

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APPENDIX A

INSTRUCTIONS FOR VELOCITY JUDGMENT STUDY CHRYSLER FCCS

1. Conditions for the Firing Tank remain the same for all engagements: SPEED, stationary; TERRAIN, Smooth; AMMO, SABOT. Initially set the target RANGE to 1500 meters, the target SPEED to 0, and the target DIRECTION to HEAD ON.

2. Tell each subject:

I'm going to ask you to tell me some things about how the picture looks in this gunnery simulator. Don't fire the main gun, just move it around and get a feel for the size and slant of that grid in front of you. That box represents a tank-sized object.

First, tell me approximately how wide the closest part of that grid is (to the nearest 50 yards or 50 meters, whichever you prefer).

About how wide is the farthest part of that grid?

About how wide is the middle of that grid? _____

About how long, to the nearest 50 yards or 50 meters (whichever you prefer) is the grid? _____

How much is the grid slanted, if 0° is flat against the ground and 90° is straight up and down (your answer can be anywhere between 0 and 90°)? _____

About how far, to the nearest 50 yards or 50 meters, does that tank-sized object appear to be? _____

The experimenter should then readjust the RANGE to 2500 meters and ask:

About how far, to the nearest 50 yards or 50 meters, does that tank-sized object appear to be now? _____

The experimenter should then readjust the RANGE to 1000 meters and ask:

About how far, to the nearest 50 yards or 50 meters, does the tank-sized object appear to be now? _____

Now I'm going to show you some displays of tank-sized objects moving either to the right or left. I want you to simply tell me how fast it is moving after each display goes off.

Instructions for Group A:

The tank-sized objects can move at one of three different speeds: a slow speed (10 mph), a medium speed (15 mph), and a fast speed (25 mph). It will move across your field of view for approximately 5 seconds, at different distances from you. Tell me how fast it is going after each trial. Do you have any questions?

Instructions for Group B:

The tank-sized object can move at any speed between 0 and 50 mph. It will move across your field of view for approximately 5 seconds, at different distances from you. Tell me to the nearest 5 mph how fast it is going after each trial. Do you have any questions?

DATA SHEET
VELOCITY JUDGMENT STUDY CHRYSLER COFT

NO RANGE INFORMATION

| ENGAGEMENT | SPEED | DIRECTION | RANGE | JUDGED VELOCITY |
|------------|-------|-----------|-------|-----------------|
| _____ | 10 | L | 1000 | _____ |
| _____ | 10 | L | 1500 | _____ |
| _____ | 10 | L | 2500 | _____ |
| _____ | 10 | R | 1000 | _____ |
| _____ | 10 | R | 1500 | _____ |
| _____ | 10 | R | 2500 | _____ |
| _____ | 15 | L | 1000 | _____ |
| _____ | 15 | L | 1500 | _____ |
| _____ | 15 | L | 2500 | _____ |
| _____ | 15 | R | 1000 | _____ |
| _____ | 15 | R | 1500 | _____ |
| _____ | 15 | R | 2500 | _____ |
| _____ | 25 | L | 1000 | _____ |
| _____ | 25 | L | 1500 | _____ |
| _____ | 25 | L | 2500 | _____ |
| _____ | 25 | R | 1000 | _____ |
| _____ | 25 | R | 1500 | _____ |
| _____ | 25 | R | 2500 | _____ |
| _____ | 10 | L | 1000 | _____ |
| _____ | 10 | L | 1500 | _____ |
| _____ | 10 | L | 2500 | _____ |
| _____ | 10 | R | 1000 | _____ |
| _____ | 10 | R | 1500 | _____ |
| _____ | 10 | R | 2500 | _____ |
| _____ | 15 | L | 1000 | _____ |
| _____ | 15 | L | 1500 | _____ |
| _____ | 15 | L | 2500 | _____ |
| _____ | 15 | R | 1000 | _____ |
| _____ | 15 | R | 1500 | _____ |
| _____ | 15 | R | 2500 | _____ |
| _____ | 25 | L | 1000 | _____ |
| _____ | 25 | L | 1500 | _____ |
| _____ | 25 | L | 2500 | _____ |
| _____ | 25 | R | 1000 | _____ |
| _____ | 25 | R | 1500 | _____ |
| _____ | 25 | R | 2500 | _____ |

GIVE RANGE INFORMATION!!

| ENGAGEMENT | SPEED | DIRECTION | RANGE | JUDGED VELOCITY |
|------------|-------|-----------|-------|-----------------|
| _____ | 10 | L | 1000 | _____ |
| _____ | 10 | L | 1500 | _____ |
| _____ | 10 | L | 2500 | _____ |
| _____ | 10 | R | 1000 | _____ |
| _____ | 10 | R | 1500 | _____ |
| _____ | 10 | R | 2500 | _____ |
| _____ | 15 | L | 1000 | _____ |
| _____ | 15 | L | 1500 | _____ |
| _____ | 15 | L | 2500 | _____ |
| _____ | 15 | R | 1000 | _____ |
| _____ | 15 | R | 1500 | _____ |
| _____ | 15 | R | 2500 | _____ |
| _____ | 25 | L | 1000 | _____ |
| _____ | 25 | L | 1500 | _____ |
| _____ | 25 | L | 2500 | _____ |
| _____ | 25 | R | 1000 | _____ |
| _____ | 25 | R | 1500 | _____ |
| _____ | 25 | R | 2500 | _____ |
| _____ | 10 | L | 1000 | _____ |
| _____ | 10 | L | 1500 | _____ |
| _____ | 10 | L | 2500 | _____ |
| _____ | 10 | R | 1000 | _____ |
| _____ | 10 | R | 1500 | _____ |
| _____ | 10 | R | 2500 | _____ |
| _____ | 15 | L | 1000 | _____ |
| _____ | 15 | L | 1500 | _____ |
| _____ | 15 | L | 2500 | _____ |
| _____ | 15 | R | 1000 | _____ |
| _____ | 15 | R | 1500 | _____ |
| _____ | 15 | R | 2500 | _____ |
| _____ | 25 | L | 1000 | _____ |
| _____ | 25 | L | 1500 | _____ |
| _____ | 25 | L | 2500 | _____ |
| _____ | 25 | R | 1000 | _____ |
| _____ | 25 | R | 1500 | _____ |
| _____ | 25 | R | 2500 | _____ |

Reset RANGE to 1500m, SPEED to 0, and DIRECTION to HEAD ON.

Again, how wide is the closest part of that grid? _____

How wide is the farthest part? _____

How wide is the middle? _____

How long, in yards, or meters is the grid? _____

How much is it slanted (again, between 0 and 90°)? _____

How far is that tank-sized object? _____

Reset RANGE to 2500m and ask:

How far is it now? _____

Reset RANGE to 1000m and ask:

How far is it now? _____

APPENDIX B

CALCULATION OF FCCS EXPECTED HIT PROBABILITIES

Hit probabilities were calculated for the strategy of using a single standard lead. This straightforward calculation yielded expected hit probabilities with a 2.5 mil lead for each target speed, and at each of the three ranges at which speed judgments were made (1000, 1500, and 2500 meters).

Hit probabilities were also determined for the lead calculation strategy suggested by Bessemer and Kraemer (1979) using speed estimation data from the Speed Magnitude Estimation group. Since estimates of target speed varied, there was actually a distribution of estimated target speeds for each physical target speed. These distributions of speeds converted to hypothetical distributions of lead when estimated target speeds were divided by 10 mph and the result multiplied by 2.5 mils, as suggested by Bessemer and Kraemer. This yielded a distribution of applied leads, and hence a distribution of hit probabilities for each physical target speed. For the sake of convenience in calculating overall hit probabilities, the experimenters assumed a normally distributed population of speed estimates, and hence a normally distributed population of hit probabilities for each target speed. Summing hit probabilities weighted by their probability of occurrence across small discrete intervals of the distribution of hit probabilities produced a single estimated hit probability for each target speed at each of the three target ranges.

This process was repeated with the data from the Speed Magnitude Estimation group, but using a multiplicative factor of 3.5 mils when converting speed estimates to lead distributions. The factor of 3.5 mils compensated optimally for observers' tendency to slightly underestimate target speed overall.

Finally, estimated hit probabilities were calculated for a 3-lead strategy in which a gunner judges whether the target's speed is either slow, medium, or fast and applies a 2.5, 5.0, or 7.5 mil lead, respectively. Hit probabilities for this strategy were calculated from the data of the Speed Categorization group by simply multiplying the proportions of slow, medium, and fast responses to a given physical target speed by hit probabilities for respective leads of 2.5, 5.0, and 7.5 mils given that target speed. Summing these products for each physical target speed yielded an expected hit probability for targets moving 10, 15, and 25 mph at each of the three target ranges.

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